TESTING OF SKID RESISTANCE OF SMOOTH FLOOR SURFACES

USING VARIOUS SIZES OF RUBBER AND LEATHER SHOE HEELS

by

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A Thesis Submitted to
the Faculty of the Graduate School at
The Woman's College of the University of North Carolina
in Partial Fulfillment
of the Requirements for the Degree
Master of Science in Home Economics

Greensboro
June, 1963

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ACKNOWLEDGMENTS

The researcher wishes to express her appreciation to the persons whose cooperative efforts made this study possible.

To Mrs. Savannah Day, who so competently directed the design and development of this study. Her interest, understanding, and kindness were a source of inspiration and encouragement throughout the study.

To Dr. Henry Bowen, who specially designed and developed the testing apparatus used in the study.

To Dr. Hildegarde Johnson, who assisted in directing the statistical analysis of the data.

To the members of the thesis committee, who contributed constructive criticisms in the writing of the thesis: Dr. Hildegarde Johnson, Dr. Anna Reardon, and Mrs. Madeleine Street.

To the laboratory assistants, who rendered capable assistance in collecting and computing data for the thesis.

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CHAPTER I

INTRODUCTION

Smooth floor surface materials are advertised and promoted mainly from the standpoint of their attractiveness and ease of maintenance. Except in technical journals, relatively little information is available on the skid resistance properties of floor surface materials for consumers to use as a criterion in selecting safe floor surfaces. This is unfortunate since much of the literature on housing for the aging and for families with young children repeatedly suggests the need for non-skid floor surfaces. It is an accepted fact that safe floors are not only important to people in these age groups but to people of all ages.

A study of fatal home accidents was conducted by the Metropolitan Life Insurance Company among its policyholders ranging between the ages of one and 74. The study was made of claim records of Industrial policyholders of this insurance company who were killed in home accidents in 1956 and of Ordinary policyholders who were killed in 1956 or 1957. The Metropolitan Life Insurance Company published the following results of the survey:

> Falls outranked by a wide margin every other type of fatal accident in the home, accounting for nearly half of the deaths in this study. About one in every three fatal falls in this insurance experience occurred on stairs and steps. Almost one-sixth of the deaths were attributed to falls of people who were merely walking about a room or going from one room to another

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on the same level.[1]

It was also found in this study that most of the falls occurred among the elderly.[2]

In corroboration with the preceding study, the 1960 edition of Accident Facts reported that 98 per cent of falls inside the home were on the same level and that the majority of these falls occurred in the bedroom. It further stated that the age groups most susceptible to fatal falls are children under five years and persons between 45 and 64 and over 65 years of age.[3]

In 1948 a survey was conducted in Sheffield County, England, using a sample of people of pensionable age to investigate the frequency and cause of falls among the elderly. Each subject was both interviewed and given a physical examination after he had experienced a fall. The results of the study indicated that falls increase with age and that women fall at an earlier age than men. The death rate from falls rapidly increased after a woman reached 65 years of age until there were about three times as many deaths from falls among women as among men. The greater domestic activity and the longer life span of women today were some of the factors found to be the cause of more falls occurring among women.[4]

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[1]"How Fatal Accidents Occur in the Home," Metropolitan Life Insurance Company Statistical Bulletin, XL (November-December, 1959), pp. 7-8.

[2]Ibid., p. 8.

[3]Accident Facts, 1960 Edition, pp. 86-88.

[4]Hugo M. Droller, M. D., "Falls Among Elderly People Living At Home," Geriatrics (May, 1955), pp. 239-241.

Falls were found to be caused by certain pathologic conditions, but the liability to fall was always linked with the opportunity to fall. Among the numerous defects found in their homes, linked with the opportunity to fall, were unsuitable floor surfaces.[5]

A large manufacturing firm of floor wax did extensive study of the causes of falls resulting from walking across floors on the same level and concluded that there were four major causes:

1. Condition and type of shoe-wear.
2. Condition of floor.
3. Physical condition of the walker.
4. Mental condition of the walker.

Of these major causes of falls, only the condition of the floor and the type of foot-wear are significantly affected by actions of the owner.[6]

The Building Research Institute, a division of engineering and industrial research with headquarters in Washington, D. C., conducted a survey in 1958 of resilient flooring problems encountered in the floor surface field. One part of the survey questionnaire was designed to find out what basic complaints existed in the resilient flooring industry as far as the ultimate consumer was concerned. One of the six basic complaints dealt with slippery floor surfaces. The flooring materials ranked according to number of complaints of slipperiness in descending order were as follows: asphalt, vinyl asbestos, vinyl (homogeneous),

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[5] Ibid., pp. 240-241.

[6] "Floor Safety is No Accident," Institutions Magazine, XLII (June, 1958), p. 56.

vinyl (backed) rubber, and linoleum.[7]

In an article entitled "Floor Safety is No Accident" in the Institutions Magazine, it has been stated that there is no method of making a floor slip-proof and that there is not likely to be one because of too many uncontrollable factors such as the kinds of floors, kinds of footwear, varying degrees of walking and watching care, and cleanliness of walking areas.[8] However, the large percentage of fatal falls among the elderly suggests a need for research that would determine the degree of slipperiness of available smooth floor surface materials. A floor surface with high skid resistance for a wide selection of shoe heel materials is desirable.

I. THE PROBLEM

This investigation is a pilot study to a larger research project entitled, "Testing of Smooth Floor Surfaces and Finishes From the Standpoint of Safety" which is sponsored by the North Carolina Agricultural Experiment Station and contributes to the Southern Regional Housing Research Project, S-8. Skid resistance characteristics and glossiness of various smooth floor surface materials as well as the effects of several types of floor finishes and moisture on the floor materials will be studied in the larger project.

The School of Home Economics at the Woman's College of the

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[7] "Installation and Maintenance of Resilient Smooth-Surface Flooring," National Academy of Sciences-National Research Council, Publication 597 (September, 1958), p. 126.

[8] Institutions Magazine, op. cit., p. 57.

University of North Carolina recently secured a skid resistance testing apparatus developed by Dr. Henry Bowen of the Department of Agricultural Engineering, North Carolina State College, for use in securing data for the above project.

The present investigation was selected for study since very little experimentation has been conducted in regard to testing the skid resistance of various kinds of resilient floor surfaces using different shoe heel materials. No tests have been made using different sizes of shoe heels. There was also a need for a pilot study to determine the use and limitations of the testing apparatus to be used in the project, "Testing of Smooth Floor Surfaces and Finishes From the Standpoint of Safety."

The purposes of the present study are as follows:

1. To determine the coefficient of friction for different sizes of leather and rubber shoe heels on smooth floor surface materials.

2. To determine whether the coefficient of friction is affected by (a) the size of the shoe heel or (b) the weight load applied to the heel.

II. DEFINITIONS OF TERMS USED

Friction. Friction is the resistance to relative motion existing between two surfaces in contact. It is caused by molecular attraction between the surfaces and also by the irregularities in the surfaces which tend more or less to interlock where the two surfaces are pressed together. Classical laws of friction state that the friction between two surfaces is independent of the area of contact and dependent on the normal force pressing the two surfaces together. Experimental results indicate that approximately a 10 per cent deviation from these laws can be expected; therefore, this experiment was partially designed to measure the amount of deviation provided by the testing apparatus developed for use in collecting data in the experiment.

Static friction. "Static friction is that friction which opposes motion when there is no slipping."[9] The coefficient of static friction may be expressed by the equation, $\mu s = \frac{F_s}{N}$, where F_s is the maximum force that can be developed without slipping and N is the normal force holding the two surfaces together.

Kinetic friction. "Kinetic friction is that friction which opposes motion when one body is slipping on the surface of another at a constant speed."[10] In the equation for the coefficient of kinetic friction, $\mu k = \frac{F_k}{N}$, F_k is the force required to slide one surface over another at a constant speed and N is the normal force holding the two surfaces together.

Resilient floor surfaces. Floor surfaces that are classified as resilient are those that are capable of resuming their original size and shape to some degree after deformation.

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[9]Ovid W. Exhback, Handbook of Engineering Fundamentals (New York: John Wiley and Sons, Inc., 1936), p. 4.

[10]Ibid.

CHAPTER II

REVIEW OF THE LITERATURE

Very little experimentation has been conducted in regard to testing the skid resistance of various kinds of resilient floor surfaces using different shoe heel materials, and there have been no tests made using different sizes of shoe heels. A brief summary of the experiments performed and other relevant material will here be given.

I. SKID RESISTANCE TESTING OF SMOOTH FLOOR SURFACES

The first laboratory study to determine the skid resistance properties of walk-way surfaces was undertaken by the National Bureau of Standards in 1926. The investigation resulted in the development of an apparatus and procedure for testing skid resistance.[1]

Specimens tested ranged from flooring materials extensively used to those less commonly used. The sample also represented extreme ranges in hardness, smoothness, absorptive power, and other characteristics affecting skid resistance. The materials were tested under controlled surface conditions and surface conditions simulating possible service characteristics. Both shoe and surface materials were worn to a certain

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[1]R. B. Hunter, "A Method of Measuring Frictional Coefficients of Walk-way Materials," Bureau of Standards Journal of Research, V (August, 1930), p. 330.

degree so that accurate skid resistance properties might be obtained and to insure the same test results at a later time.[2]

The testing apparatus consisted of a right-angled frame carrying a slotted 75 pound weight. A shoe material could be drawn forward over a surface material fastened on the testing surface and the horizontal force increased until the shoe slipped, letting the weight drop. A graduated scale read the amount of force necessary to overcome the friction between the shoe and surface materials.[3]

The results of the study indicated that the method of friction testing needed further development in order to rate materials according to skid resistance properties.[4]

The National Safety Council and the National Bureau of Standards undertook a joint research project in order to provide data that could be used in developing a code for safe walkway surfaces. The development of such a code had been hindered materially because of a lack of an adequate method of measuring slipperiness.[5]

Preliminary to the design of a practical testing apparatus to be used in this joint project for measuring the skid resistance of walkway surfaces, a study was conducted of the mechanics of the human gait. Slow

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[2]Ibid., pp. 330-332.

[3]Ibid., p. 333.

[4]Ibid., p. 346.

[5]Thomas H. Boone, Martin N. Geib, Percy A. Sigler, "Measurement of the Slipperiness of Walkway Surfaces," Journal of Research of the National Bureau of Standards, XL (May, 1948), p. 339.

motion cameras were used to photograph people as they were walking. The cameras were concealed so that people were unaware of being photographed, and, therefore, were walking naturally. The pictures taken revealed the following description of the human gait:

> The leg slows down at the termination of its swing and then appears to vault onto the walkway, the other leg being used as a pole. The foot is first placed upon the walkway at an angle so that only the rear edge of the heel contacts the walkway surface during the early stages of the retarding phase of a step. The other foot remains in contact with the walkway, thus bearing part of the vertical load, until the heel rocks forward and the foot is fully planted.
>
> The horizontal component of the force exerted by the leg on a walkway surface reaches a maximum in the forward direction shortly after the heel makes contact with the walkway, decreases rapidly at first and then slowly as the foot deploys, and rapidly reaches a maximum in the backward direction as the ball of the foot prepares to leave the walkway. These horizontal components are the forces that must be counteracted by friction in order to avoid slipping.[6]

In relation to the above mentioned project, the Sigler Pendulum-Impact Type Slipperiness Tester was designed as a laboratory instrument for evaluating small test panels and for testing floors in actual service. The design of the machine was based on the premise that in the process of walking, slipping is most likely to occur when the walkway is first contacted by the heel. The tester, planned and constructed by the National Bureau of Standards, consisted of a pendulum that had at the lower end of it a mechanical heel to which a heel material could be impacted and swept over the surface to be tested. Because of vibrations which resulted from the impact of the mechanical heel on the walkway,

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[6] Ibid., p. 340.

the instrument was not considered suitable for testing very rough or embossed surfaces. Dynamic friction was the type of friction measured by this machine.[7]

Statistical analyses of the data obtained from the machine indicate a standard deviation from the means which ranged from 0.01 to 0.03. From three to five results for each condition measured were averaged to obtain representative values.[8]

Angles of contact between the heels and surface materials, which were 10, 20, and 30 degrees, slightly affected the skid resistance properties. With an increase in the angle of contact, there was a decrease in the skid resistance. The variance was so minute that an angle of 20 degrees was adopted for general use.[9]

When the amount of pressure was varied by using helical springs on the mechanical heel exerting an average force of 3.7, 6.7, and 11.2 pounds, appreciable difference in the results was noted. Generally it was found that the greater the pressure, the lower the skid resistance. A similar difference was observed when worn and unworn heels were used. However, no tests were made using heels of different sizes.[10]

Practically all surfaces tested, including such resilient flooring materials as rubber, linoleum, and asphalt, gave a higher coefficient of

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[7] Ibid., pp. 340-341.

[8] Ibid., p. 342.

[9] Ibid.

[10] Ibid.

friction for dry rubber heels than for dry leather heels; but when wet, many surfaces would be considered dangerous for both rubber and leather footwear. When asperities that projected through the film of water were present, the coefficient of friction measurements were higher.[11]

The following conclusion was drawn as a result of the tests performed:

> The results of these tests, considered in relation to slipperiness as actually experienced, indicate that a slippery condition does or does not exist according to whether the measured coefficient is less or greater than 0.4.[12]

This information was not corroborated by Schjodt, a research engineer at the Norwegian Building Research Institute in charge of research and control of floors and floor surfaces. He reported in 1960 on the relative slipperiness of a variety of walkway surfaces measured during a test recording human reactions to the hardness of floor coverings. This testing was done simply by pulling a weighted sole along the floor. The friction angle was also measured by using special test floors that could be tilted. The results of the Schjodt study indicated that the friction ought not to be less than 0.20 and not more than 0.40 for leather soles.[13]

The Hospital Bureau, Incorporated in New York City, New York, reported in 1958 a simple method for determining whether a floor is

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[11] Ibid., p. 343.

[12] Ibid., p. 346.

[13] R. Schjodt, "Measurement of Human Reaction to Hardness of Floor Coverings," American Society for Testing Materials, Bulletin No. 247 (July, 1960), pp. 53-56.

slippery. A weighted bag is slowly pulled across the floor to be tested with a spring scale. The floor is considered slippery if it takes less than three pounds to move the bag, but it is considered safe if five pounds or more is required.[14]

The James machine developed by S. V. James of Underwriter's Laboratories measures static friction in contrast to the Sigler Slipperiness Tester. It may be used to test wet, rough, or corrugated surfaces. The testing surfaces on the machine are advanced forward until a particular shoe material slips and a vertical column drops. The coefficient of friction is estimated to the nearest 0.01 at the top of the vertical drop line.[15]

Another testing apparatus which operates on the same principle as the James machine is the Dura Slip Resistance Tester. Investigations into the use of this machine have indicated that it is suitable for determining the coefficient of static friction measurements ranging between 0.088-1.000.[16]

An article in the 1958 American Society for Testing Materials Bulletin states that both the Sigler and James machines provide inadequate

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[14]"Simple Slip Test for Wax," Bureau Research News, V (December, 1958), p. 3.

[15]"Proposed Method of Test for Measuring the Static Coefficient of Friction of Waxed Floor Surfaces," American Society for Testing Materials Bulletin, No. 196 (February, 1954), pp. 20-21.

[16]Bernard Berkeley and James D. Burns, "Floor Wax Slip Testing-Statistical Analysis of Dura vs. James Coefficient of Friction Measurements," Soap and Chemical Specialities, XXXIII, No. 4 (April, 1957), pp. 77-80.

methods for testing skid resistance properties of walkway surfaces because the measurements of the coefficient of friction provided by both machines do not always correlate with foot tests conducted on the floor. A further statement made was that "there are presently no standards of floor safety that can be expressed in terms of accident frequency, coefficient of friction, or subjective foot tests conducted in the field."[17]

II. THE FIRST LABORATORY STUDY OF SKID RESISTANCE OF HIGHWAY SURFACES

The first laboratory tests in the United States measuring the skid resistance properties of passenger car tires on pavement surfaces were made in 1937-38 at the University of Minnesota.

As with floor surfaces it is difficult to reproduce in the laboratory actual field test conditions; however, important variables can be controlled in laboratory tests. Because of this control, the effect of certain variables on skid resistance properties may be determined.[18]

The Leroux pendulum apparatus, similar in construction to the Sigler slipperiness tester, was used in collecting the data for the tests. A strip of tire tread rubber was forced to follow a certain length of the surface of a test sample. The pressure of the rubber against the sample

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[17]"Evaluating the Slip Resistance of Floor Waxes, The Significance of Friction Measurements," American Society for Testing Materials Bulletin, No. 232 (September, 1958), p. 32.

[18]International Skid Prevention Conference Proceedings, First Part 1, Virginia Council of Highway Investigation and Research, 1959, pp. 230.

was regulated. A coefficient of friction of .45 was found to be the limit between slippery and non-slippery surfaces due to the occurrence of 65 per cent of all skidding accidents taking place on road surfaces with friction measurements equal to or less than this value. It is interesting to note that the conclusions drawn from the Sigler tests for flooring materials and the Leroux tests for road surface pavements were similar.[19]

III. SKID RESISTANCE TESTING OF STAIRWAY TREADS

The Agricultural Engineering Department at Michigan State University in cooperation with the North Central Farm Housing Committee recently completed a study geared to establishing quantitative measurements of skid resistance characteristics of stairway tread covering materials and various combinations of shoe sole materials.[20] Two ranges of shoe sole sizes including those for men's shoes and those for women's were tested to determine the effect of the area of contact upon frictional measurements.[21] The project yielded results that were valuable in classifying available stair tread and shoe sole materials from a safety standpoint.[22] The study was initiated because a survey of 100 stairway accidents in Ingham County, Michigan, indicated that 38 per cent of the

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[19] *Ibid.*, pp. 313-315.

[20] *Michigan Contributing Project Report for 1959*. (Mimeographed.)

[21] Merle L. Esmay, *Home Stairway Safety Research Results*, p. 10. (Mimeographed.)

[22] *Michigan Contributing Project Report for 1959*, *loc. cit.*

stairway accidents were caused by slipping.[23]

For the preliminary tests a portable testing machine was developed with the idea of transporting it from one stairway to another. This machine proved to be inadequate because it failed to lend itself to experimental control for laboratory tests in which consistent and repeatable results are necessary.[24]

A second machine designed for the project consisted of a movable table to which a tread material was fastened and pulled under a shoe sole. The horizontal force required to move the testing surface under the sole was recorded on an oscillograph and divided by a known vertical force applied on the shoe sole material to calculate the coefficient of friction for various materials.[25]

Results of the tests indicate that slipping on a stair tread will occur when the ratio of the horizontal force to the vertical force is greater than the coefficient of friction for the tread material.[26]

Four different conditions were simulated using various combinations of new and worn shoe sole and tread materials. This experimental design was considered appropriate because a high coefficient of friction is desirable for worn and new tread materials when they are in contact with

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[23]Esmay, _op_. _cit_., p. 5.

[24]_Michigan Contributing Project Report for 1959_, _loc_. _cit_.

[25]_Ibid_.

[26]Merle Esmay and Larry J. Segerlind, "Analysis of the Frictional Characteristics of Stairway Tread Covering Materials," Paper No. 60-914, p. 5. (Mimeographed.)

a wide selection of shoe sole materials.[27]

Of the six materials tested including an abrasive strip, varnished wood, rubber mat, painted wood, untreated wood, and linoleum, the abrasive strip gave the highest over-all coefficient of friction while linoleum gave the lowest. There was a decrease in the coefficient of friction after all of the materials were worn except for linoleum and rubber.[28]

Shoe sole materials tested included ripple, neoprene, neolite, crepe, Goodrich, and leather. Ripple exhibited the highest coefficient of friction; but leather, which performed the poorest of all materials used in the experiment, gave a coefficient of friction much less than half that of the ripple sole. The coefficient of friction for all materials increased after the materials were worn except for crepe.[29]

For all shoe sole materials except for the ripple sole, a reduction of the coefficient of friction was measured for the small soles as compared to the large soles.[30]

IV. CONCLUSION

The results of the majority of these studies suggest the need for the development of an improved method of testing walk-way surfaces for skid resistance properties. This information would prove valuable in

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[27] Merle L. Esmay, op. cit., p. 8.

[28] Ibid.

[29] Ibid., p. 10.

[30] Ibid.

ranking flooring materials from the standpoint of safety for the benefit of the ultimate consumer.

Although studies of skid resistance properties of walk-way surface materials have been conducted since 1926, no standards for safe walk-ways have been made available. However, the National Bureau of Standards, in an effort to fulfill this need, has developed surfaces designed to serve as standards in the calibration of instruments for measuring the co-efficient of friction of floor, walkway, and highway surfaces. "The surface characteristics of these standards will be transferred to secondary standards of other materials, including softer metals, for use by selected laboratories with a variety of instruments for measuring slipperiness." These standards will probably become available after further testing is conducted.[31]

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[31] Research Highlights of the National Bureau of Standards Annual Report, Miscellaneous Publication 237 (December, 1960), p. 113.

CHAPTER III

EXPERIMENTAL PROCEDURE

The procedures used for the preparation and testing of the floor surface and heel materials in the study were based upon those used in previous studies of skid resistance properties of walk-way surfaces. In this chapter, the testing apparatus, the procedures for the preparation and testing of the floor surface and heel materials, and the method used in the analyses of the data will be discussed.

I. THE TESTING APPARATUS

The skid resistance testing apparatus, designed and constructed for this study, was used to obtain kinetic friction measurements for a number of combinations of different sizes of leather and rubber shoe heels and various smooth floor surface materials. These values were then used in computing the coefficient of kinetic friction, the measurement of interest in the experiment.

The testing machine consists chiefly of a movable circular table, powered by a controllable speed electric motor, and a mechanical recorder, which records the force of friction existing between the various floor and heel materials (Figure 1). A minute pin, attached to the recording instrumentation, records the test results using recording ink on General Electric record rolls (Figure 2). The pin was completely free of any undue tension in order for it to be sensitive to differences in the amount of force required to slide one surface over

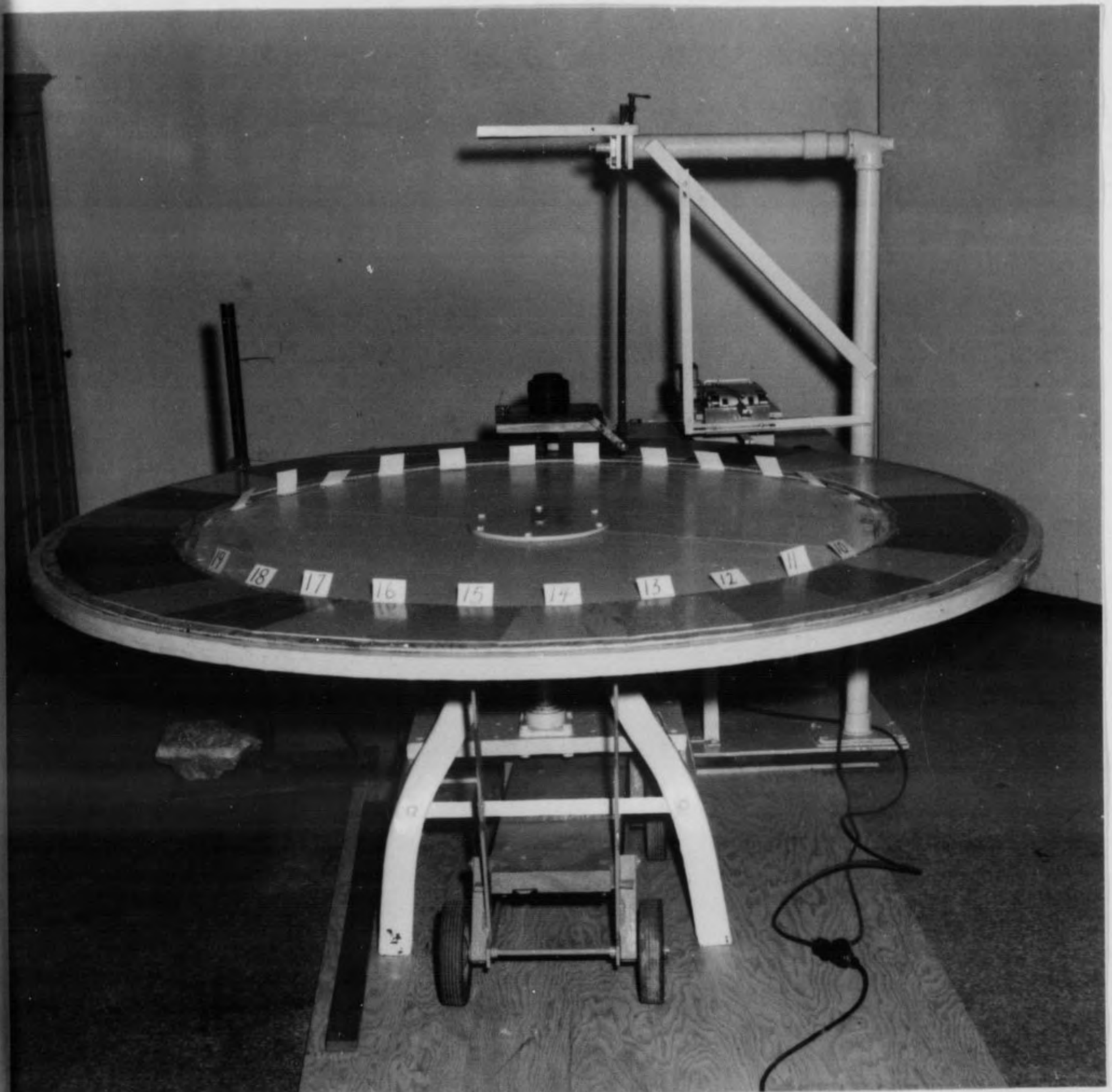


FIGURE 1

THE FRICTION TESTING APPARATUS

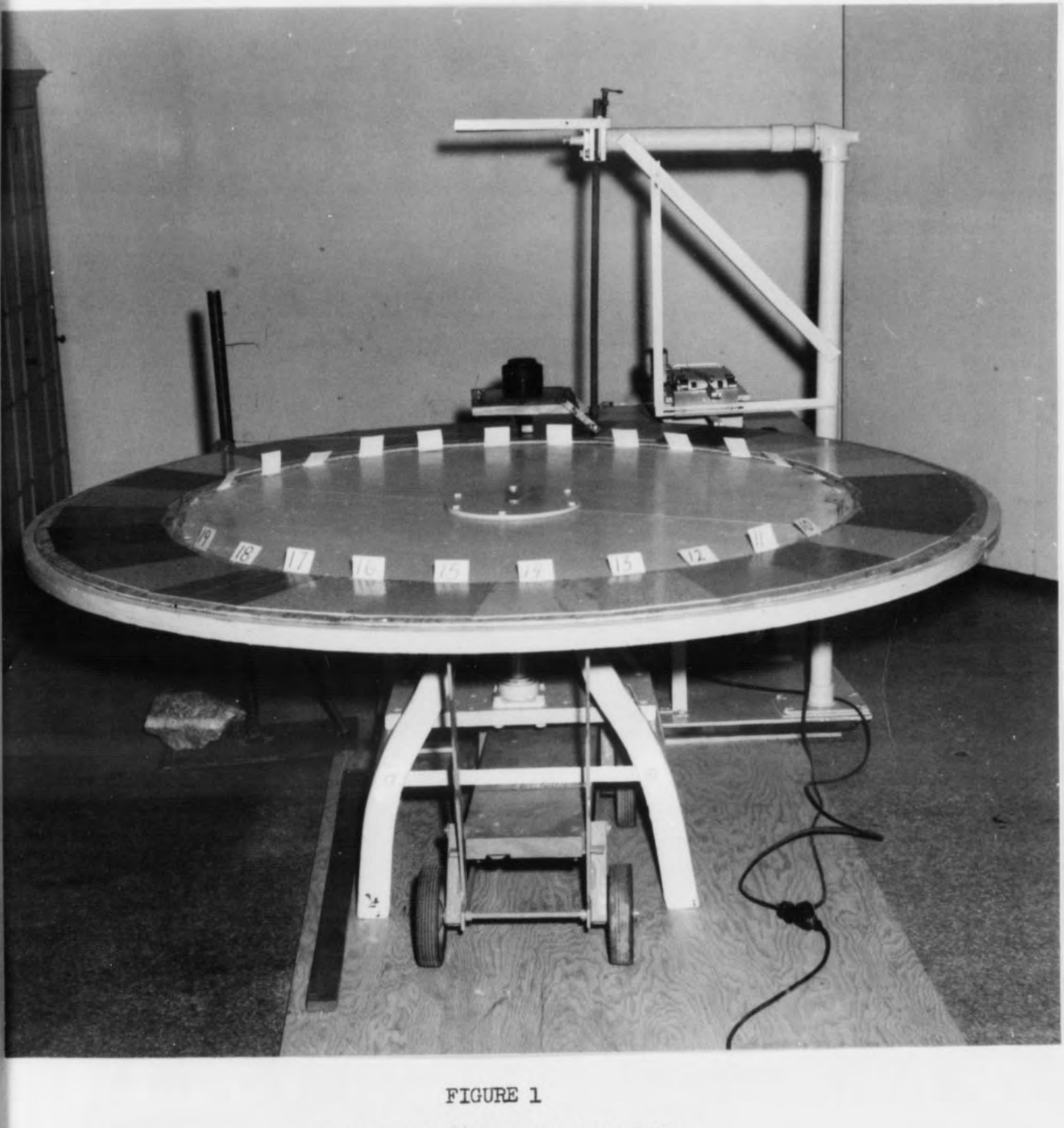


FIGURE 1

THE FRICTION TESTING APPARATUS

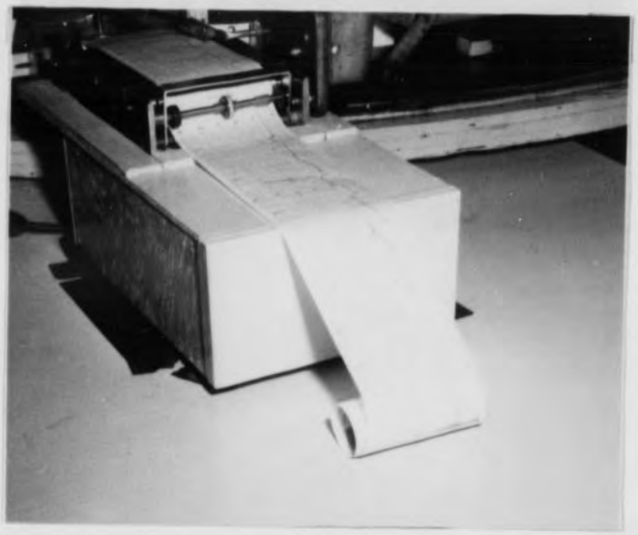


FIGURE 2

THE MECHANICAL RECORDER

another. Precautions were taken to reset the pin on the zero line on the record rolls before each test was made.

The testing surface of the machine consisted of a plywood ring, three-eighth inch in thickness, to which 28 test panels of floor surface materials were cemented. Each plywood ring was attached individually to the top surface of the circular table to allow materials on other plywood rings to be tested.

Each shoe heel was mounted on a wooden block which was fastened with winged nut screws to a weight platform on the machine (Figure 3). The heel, loaded with the desired amount of weight, was held stationary while the testing surface containing the flooring materials revolved underneath it at a constant speed.

Load beams ranging in size from three-fourth inch to one inch in

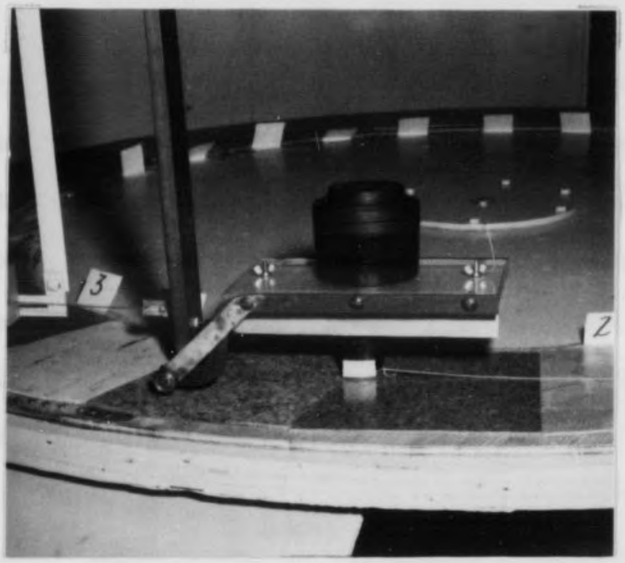


FIGURE 3

THE WEIGHT PLATFORM WITH ATTACHED SHOE HEEL

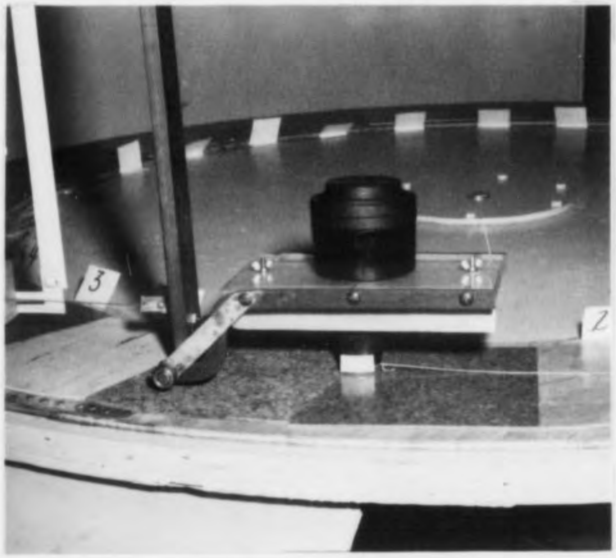
thickness were used to support the weight platform. The smaller bar, used when the lesser weights were placed on the heels, provided an amplification of the readings recorded by the mechanical recorder; but the larger bars supported greater weights on the various heel sizes and decreased proportionately the force of friction readings given by the heavier weights.

The testing machine measures both kinetic and static friction, but only kinetic friction measurements were obtained in this particular study.

II. PREPARATION FOR TESTING

Selection of Floor Surface Materials

Three samples of each floor surface material tested were secured



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The testing machine measures both kinetic and static friction, but only kinetic friction measurements were obtained in this particular study.

II. PREPARATION FOR TESTING

Selection of Floor Surface Materials

Three samples of each floor surface material tested were secured from each of two manufacturers of flooring materials. These six samples were used as replications of each material in the experiment. The sample included nine different resilient floor surface materials, providing a total of 54 test panels. Two plywood rings were necessary to accommodate this number of panels. In order for the test panels to fit the circular testing surfaces, each panel had to be cut in the shape of a trapezoid and placed with the narrower side toward the center of the plywood ring. Since two plywood rings hold a possible 56 test panels, there were two extra spaces on the testing surfaces which were filled with panels of asphalt-asbestos. These panels were not used in the over-all results of the experiment. The materials represented in the sample were confined to those that met the requirements of federal specifications. The materials tested, the manufacturer, and the federal specification numbers are listed in Table I.

The materials tested were representative of nine different floor surface manufacturers. The following descriptions of resilient smooth surface flooring materials were given by the floor surface industry at a conference conducted by the Building Research Institute in Washington, D. C., in September, 1958:

> _Asphalt tile_. Composed through full thickness of asphaltic or resinous binder with asbestos or other fibers, filler, and pigments formed under pressure while hot.
>
> _Vinyl-asbestos tile_. Composed through full thickness of vinyl resins, plasticizers, pigments, fillers and asbestos fibers formed under pressure while hot.
>
> _Cork tile_. Composed through full thickness of compressed granulated cork bonded with a heat processed resinous binder.
>
> _Rubber tile_. Composed through full thickness of vulcanized rubber compound binder with reinforcing fibers, pigments

TABLE I

MANUFACTURERS AND FEDERAL SPECIFICATION NUMBERS OF FLOORING MATERIALS TESTED

Floor surface materials	Manufacturer	Federal Specifications
Asphalt	Armstrong Cork Co. Flintkote Co.	SST-306b
Vinyl asbestos	Kentile, Inc. Flintkote Co.	L-T-00345(COM NBS)
Plain cork	Kentile, Inc. Armstrong Cork Co.	LLL-T-341b
Vinyl cork	Armstrong Cork Co. Dodge Cork Co.	LLL-T-431b
Rubber	B. F. Goodrich Co. Kentile, Inc.	ZZT-301b
Greaseproof asphalt	Kentile, Inc. Flintkote Co.	SS-T-307(GSA-FSS)
Battleship linoleum	Armstrong Cork Co. Congoleum-Nairn, Inc.	LLL-L-351b
Solid vinyl translucent	Amtico Flooring Div., American Biltrite Rubber Co. The General Tire & Rubber Co.	LF-00450
Solid vinyl opaque	Kentile, Inc. Robbins Floor Products, Inc.	LF-00450

and fillers.

Linoleum tile. Composed of oxidized linseed oil, fossil and other resins or other oxidized oleo-resinous binder mixed with ground cork, wood flour, mineral fillers and pigments and pressed on burlap or saturated felt backing.

Vinyl (homogeneous) tile. Composed through full thickness of vinyl resin, plasticizers, pigments and fillers formed under pressure while hot.[1]

Placement of Test Panels on Testing Surface

After the materials were selected for testing, a table of random numbers was used to assign each test panel a specific position on the testing surface of the machine. The panels were cemented to the plywood rings with Weldwood Perma-set glue and allowed to dry for 48 hours before the first tests were conducted.

Preparation of Test Panels for Testing

The majority of falls probably take place on floor surfaces that are worn to some degree; therefore, all test panels were sanded before they were tested. Justification for this procedure is found in previous studies conducted to test skid resistance properties of walk-way surfaces. These tests indicate that the coefficient of friction is higher for new materials than for materials subjected to wear. Friction measurements become constant after approximately 15 to 20 tests have been performed on the materials.[2]

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[1]"Installation and Maintenance of Resilient Smooth-Surface Flooring," National Academy of Sciences-National Research Council, Publication 597 (September, 1958), p. 81.

[2]Thomas H. Boone, Martin N. Geib, Percy A. Sigler, "Measurement of the Slipperiness of Walkway Surfaces," Journal of Research of the National Bureau of Standards, XL (May, 1948), p. 342.

The materials were prepared in the laboratory by sanding them with carborundum paper number 400 A Tri-m-ite, as suggested by the American Society for Testing Materials.[3] The carborundum paper was mounted over a rubber pad on a wooden block, similar in construction to the wooden blocks on which the heels were mounted. This sanding apparatus was fastened to the weight platform on the friction testing machine in the same manner in which the heels were fastened to it. The sanding apparatus remained fixed during 20 revolutions of the testing surface.

Selection of Heel Sizes and Materials

Rubber and leather heel materials were selected for use in the experiment because they are two of the most common heel materials. The rubber and leather materials, each from the same sample run, were manufactured by the B. F. Goodrich Company and the Armour Leather Company, respectively. Five different sizes of heels; a spike heel, a stacked heel, a cuban heel, a child's or woman's flat heel, and a man's heel; were chosen to study the effects of the area of contact upon the coefficient of kinetic friction (Figure 4). It was considered desirable to include a child's heel in the sample since falls are common among the younger generation as well as among the elderly.

Preparation of Heel Surfaces for Testing

Carborundum paper was again used to remove the design and any surface roughness from the face of the heels so that the entire area of

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[3]"Proposed Method of Test for Measuring the Dynamic Coefficient of Friction of Waxed Floor Surfaces," American Society for Testing Materials Bulletin, Bulletin No. 196 (February, 1954), p. 21.

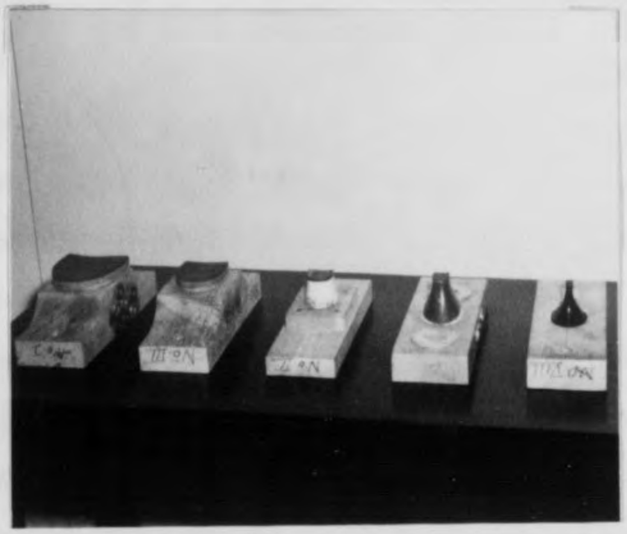

FIGURE 4

THE FIVE SHOE HEEL SIZES USED IN THE EXPERIMENT

the heel could make contact with the testing surface of the machine. The load beam was adjusted after each heel was mounted on the weight platform to allow the heel to make complete contact with the surface to be tested.

<u>Choice of Weight Loads</u>

The choice of weight loads used in the experiment was based upon a study of pressures on the human foot in walking which was conducted in Australia in 1953. Results of the study indicated that there was a poor correlation, .35, between a person's weight and the amount of pressure exerted by the heel on the floor during walking.[4] The maximum pressure

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[4]"Pressures on the Human Foot During Walking," <u>Australian Journal of Applied Science</u>, III (1953), p. 411.

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exerted by most of the subjects in the study ranged between 20 and 30 pounds per square inch; but for all subjects tested, the pressures ranged from seven to 45 pounds per square inch.[5]

Using the Australian study as a guide, weight loads of 7, 15, 25, 35, and 45 pounds per square inch were chosen for this investigation. These selected weight loads were then converted to pounds per three-fourth inch since one heel size used in the experiment was of this size. Consequently, weight loads to the nearest one-fourth pound consisting of 5, 11, 18.5, 26, and 33.5 pounds were tested on each heel size. However, on only one heel size (the three-fourth square inch) was the pressure comparable to the amount of pressure on the heel during walking as reported in the Australian study.

The amount of pressure (pounds per square inch) on each heel size is shown for the individual weight loads in Table II. The area of the heels was determined by inking each heel and securing imprints of the heels on centimeter graph paper. The number of centimeters within the imprints were counted and converted into square inches. Using the formula $P = \frac{F}{A}$, the number of square inches in a heel was divided into the various weight loads to determine the pressure (pounds per square inch) on the heels during the testing procedure.

Order of Testing Weight Loads

The order of testing the various weight loads on the shoe heels was controlled because it was not known how much weight some of the smaller

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[5]*Ibid.*, p. 416.

TABLE II

POUNDS PER SQUARE INCH ON HEEL SIZES

Heel size	Area of heel (sq. in.)	Weight load 5 lbs.	11 lbs.	18.5 lbs.	26 lbs.	33.5 lbs.
Spike heel	.09	55.56	122.22	205.56	288.89	372.22
Stacked heel	.74	6.76	14.86	25.00	35.14	45.27
Cuban heel	1.50	3.33	7.33	12.33	17.33	22.33
Child's heel	5.23	0.96	2.10	3.54	4.97	6.41
Man's heel	10.00	.50	1.10	1.85	2.60	3.35

heel sizes would support without either breaking or damaging the test panels. Also the heavier weights required a larger load beam to provide less amplification of the higher readings given by the increased weights. Thus, it seemed both practical and convenient to test increasing weight loads on the heels.

III. TESTING PROCEDURE

Order of Testing

Five heel sizes of rubber and of leather materials using five weight loads on each heel were tested in the order shown by Tables III and IV. A table of random numbers was used to randomize the order of testing the various heels.

It was impossible to perform all of the proposed tests because during the forty-third test on the first plywood ring, the spike leather heel broke under the pressure of the heavy weight load. The forty-fifth and forty-sixth tests using the spike rubber heel were omitted from the experiment as well as all tests involving the use of the spike heels on the second plywood ring.

Sizes of Load Beams Used in Experiment

The three-fourth inch load beam was used in the first tests with lighter weight loads while the one inch load beam was used to support the heaviest weight loads in the latter tests.

Method of Cleaning Materials

All test panels were washed with a detergent and allowed to dry thoroughly prior to the testing procedure. Before each test was con-

TABLE III

ORDER OF TESTING WEIGHT LOADS
ON HEEL SIZES OF RUBBER AND OF LEATHER
ON FIRST PLYWOOD RING

Heel sizes	Weight loads				
	5 lbs.	11 lbs.	18.5 lbs.	26 lbs.	33.5 lbs.
Man's rubber heel	1	2	3	4	35
Cuban rubber heel	5	6	36	37	38
Child's rubber heel	7	8	9	39	40
Man's leather heel	10	11	12	13	41
Cuban leather heel	14	15	16	17	42
Spike leather heel	18	19	20	21	43
Stacked leather heel	22	23	24	25	44
Spike rubber heel	26	27	28	45	46
Child's leather heel	29	30	31	47	48
Stacked rubber heel	32	33	34	49	50

NOTE: This table should be read as follows: Tests, one, two, three, and four were conducted using 5, 11, 18.5, and 26 pounds of weight, respectively, on the man's rubber heel. At this point it became necessary to replace the three-fourth inch load beam with the one inch load beam because of the higher readings given by the heavier weight loads. To avoid changing the load beams more than once, other tests using smaller weight loads were conducted before the three-fourth inch load beam was replaced. The solid black line indicates when the load beam was changed for tests using heavier weight loads.

TABLE IV

ORDER OF TESTING WEIGHT LOADS
ON HEEL SIZES OF RUBBER AND OF LEATHER
ON SECOND PLYWOOD RING

	Weight loads				
Heel sizes	5 lbs.	11 lbs.	18.5 lbs.	26 lbs.	33.5 lbs.
Man's rubber heel	1	2	21	22	23
Cuban rubber heel	3	4	24	25	26
Child's rubber heel	5	6	27	28	29
Man's leather heel	7	8	9	30	31
Cuban leather heel	10	11	12	32	33
Stacked leather heel	13	14	15	34	35
Child's leather heel	16	17	18	36	37
Stacked rubber heel	19	20	38	39	40

NOTE: The solid black line indicates when the load beam was changed for tests using heavier weight loads.

ducted, adhering dust was removed from the face of the heel and from the test panels by wiping them with a clean, dry cloth. This step was considered necessary because preliminary test results indicated that surfaces, which were not cleaned before testing, had a higher coefficient of friction than those surfaces free of foreign matter.

Calibration of Recorder

A recorder reading was made before and after the tests with each heel in order to calibrate. The purpose of calibrating was to provide a means by which the recorder readings could be accurately converted into pounds of frictional force. Preliminary tests on rubber and leather heels indicated that as the pressure increased force of friction increased for small rubber heels. The number of pounds of weight used in a calibration depended upon the amount of frictional force anticipated in a test.

One complete calibration consisted of adding singly a number of one pound weights to a Nylon cord attached to the heel, which was lifted approximately one-sixteenth inch above the testing surface, and then removing the weights one by one. The means of two calibrations, taken before and after each heel tested, was plotted on a graph and a line drawn between the plotted points.

Computation of the Coefficient of Friction

Four determinations or four complete revolutions of the testing surface on the friction testing apparatus, were made in each of the tests conducted. The mean of the four determinations for each test panel was read from the calibration graph as the amount of force in pounds required to overcome friction between a particular heel size of a given material and a floor surface material. The weight load, which was centered directly above the heel on the weight platform during testing, was then divided into the force of friction to compute the coefficient of kinetic friction for the two surfaces.

IV. METHOD OF DATA ANALYSIS

One of the two purposes of this study was to determine whether significant differences existed between the friction measurements for various combinations of leather and rubber shoe heel sizes and smooth floor surface materials. The second purpose of the study was to determine whether the coefficients of friction were affected by varying the weight load applied to the heels during the testing procedure.

Assuming that the materials composing the floor surface panels used in the experiment were like those in home installations and assuming that the friction testing machine provided adequate and correct measurements, the following series of hypotheses were tested:

> There are no differences in the force of friction measurements existing: (1) among different heel sizes; (2) between leather and rubber heel materials; and (3) among smooth floor surface materials and there are no first order or second order interactions between the three main effects--heel sizes, heel materials and floor surfaces.

An additional hypothesis tested was as follows:

> There is no difference in the coefficients of friction existing among shoe heels loaded with different weight loads.

The Department of Experimental Statistics at the North Carolina State College was consulted in reference to the analysis of variance model to be used in analyzing the data in the experiment. The following splitplot design was recommended and used for analyzing the data by individual weight loads:

Source of variation	Degree of freedom
Among replicates	5
Among shoe heel sizes	3
Between heel materials	1
Shoe heel sizes x materials interaction	3
Error (a)	35
Sub-units	
Among floor surfaces	8
Floor surfaces x heel sizes interaction	24
Floor surfaces x heel materials interaction	8
Floor surfaces x heel sizes x materials interaction	24
Error (b)	320
Total	431

A separate analysis of variance model was used for analyzing the effects of the five weight loads applied to the heels during testing. The following model was employed:

Source of variation	Degree of freedom
Among weight loads	4
Within loads	2155
Total	2159

The formulas used in testing for significant differences among means for the variables classified by individual weight loads and for differences among weight loads may be found in the Appendix.

Force of friction measurements were used in obtaining sums of squares for the analysis of variance by individual weight loads while the coefficients of friction were employed in the analysis of variance of all weight loads. Since the weight load applied to the heels was a factor in determining the coefficients of friction, it was considered necessary to use this measurement in the latter analysis of variance.

The F ratios for the main effects and their interactions and for the sub-units and their interactions were determined by dividing the mean squares by the mean squares of error (a) and error (b), respectively. The value of F provided a basis for testing the significant differences among variables in the experiment. The .01 level of significance was employed in order to lessen the risk of either a Type I or Type II error.

In order to interpret the findings it was necessary to compute the mean force of friction and the coefficients of friction for the floor surface materials and for the leather and rubber heels in the four different sizes.

The experimental results will be found in the following chapter.

CHAPTER IV

EXPERIMENTAL RESULTS

In this chapter the findings of the experiment performed will be discussed. Since the data were analyzed according to weight loads, the analysis of variance and the coefficients of friction will be discussed and compared for the individual weight loads and the floor surface materials ranked according to coefficients of kinetic friction. In conclusion, the findings resulting from the analysis of variance for all weight loads will be discussed.

I. ANALYSIS OF DATA FOR THE FIVE POUND WEIGHT LOAD

Analysis of Variance

The findings from the analysis of variance for the five pound weight load are presented in Table V.

For the five pound weight load, all sources of variation in the main plot were highly significant except the variation among shoe heel sizes. These findings led to rejecting the null hypotheses that there are no differences in the force of friction measurements between rubber and leather heel materials and there is no interaction between shoe heel sizes and materials, and not rejecting the hypothesis that there is no difference in the force of friction measurements existing among different heel sizes.

Among the sources of variation in the sub-units analyzed for the five pound weight load, the F ratios among floor surfaces, floor surfaces

TABLE V

ANALYSIS OF VARIANCE OF FORCE OF FRICTION MEASUREMENTS OF FLOOR SURFACES WITH DIFFERENT HEEL SIZES OF LEATHER AND RUBBER LOADED WITH FIVE POUNDS OF WEIGHT

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among replicates	5	29.50	5.90	19.67**
Among shoe heel sizes	3	1.62	.54	1.80
Between heel materials	1	131.22	131.22	437.40**
Shoe heel sizes x materials interaction	3	11.58	3.86	12.87**
Error (a)	35	10.52	.30	
Sub-units				
Among floor surfaces	8	20.55	2.57	18.36**
Floor surfaces x heel sizes interaction	24	1.46	.06	.43
Floor surfaces x heel materials interaction	8	10.62	1.33	9.50**
Floor surfaces x heel sizes x materials interaction	24	25.14	1.05	7.50**
Error (b)	320	44.11	.14	
Total	431	286.32		

**Significant beyond the .1 per cent level.

x heel materials interaction, and floor surfaces x heel sizes x materials interaction were highly significant. These findings led to rejecting the null hypotheses that there are no differences in the force of friction measurements existing among different resilient smooth floor surfaces and there is no interaction between floor surfaces and heel materials and among floor surfaces, heel sizes and materials.

The means of the force of friction measurements for each of the six replicates for the five pound weight load in the experiment were as follows:

Replicate	Mean
1	1.70
2	1.72
3	1.99
4	2.09
5	2.37
6	2.33

It may be noted that the means tended to increase with the replicates performed; however, there was no reasonable explanation for the significance of the differences among the means.

The mean force of friction for the rubber heel material, 2.58, was greater than the mean for the leather heel material, 1.48. This difference between the two heel materials indicates that rubber material, when tested under the conditions of the experiment, had greater skid resistance than leather material.

The means of the force of friction measurements for the shoe heel sizes x materials interaction for the five pound weight load are presented in Table VI.

TABLE VI

MEAN FORCE OF FRICTION MEASUREMENTS FOR LEATHER AND RUBBER HEELS OF VARIOUS SIZES LOADED WITH FIVE POUNDS OF WEIGHT

Heel size	Heel material	
	Leather	Rubber
Stacked	1.29	2.63
Cuban	1.38	2.87
Child's	1.59	2.40
Man's	1.69	2.45

When the size of the leather heels increased, the force of friction measurements increased consistently; whereas, with the rubber heels, the measurements increased with the cuban heel but decreased with the child's and man's heels.

The floor surface materials are arranged as follows in order to indicate the rankings and the range of the means of the force of friction measurements among all materials tested with five pounds of weight.

Floor surface material	Mean
Linoleum	1.69
Vinyl asbestos	1.85
Solid vinyl translucent	1.89
Asphalt	1.92
Vinyl cork	1.92
Greaseproof asphalt	2.19
Solid vinyl opaque	2.22
Rubber	2.24
Plain cork	2.38

Linoleum with a mean of 1.69, ranked lowest among all of the materials; whereas plain cork, with a mean of 2.38, ranked highest. The range between the two materials was .69. Logically, those materials with the highest force of friction measurements have greater skid resistance when tested under the conditions of the experiment.

The means of the force of friction measurements for the floor surfaces x heel materials interaction for the five pound weight load are presented in Table VII.

TABLE VII

MEAN FORCE OF FRICTION MEASUREMENTS FOR FLOOR SURFACES AND LEATHER AND RUBBER HEELS LOADED WITH FIVE POUNDS OF WEIGHT

Heel material	Floor surface material								
	Linoleum	Vinyl asbestos	Vinyl cork	Greaseproof asphalt	Solid vinyl translucent	Asphalt	Solid vinyl opaque	Rubber	Plain cork
Leather	1.28	1.29	1.33	1.36	1.37	1.44	1.54	1.60	2.10
Rubber	2.09	2.40	2.50	3.03	2.40	2.41	2.90	2.89	2.64

The significance of this interaction may be explained by the fact that the force of friction measurements for the different floor surface materials did not increase or decrease in the same order for the two heel materials. This indicated that the effect of the particular type of heel material depended upon the floor surfaces to which it was applied.

Coefficient of Friction Measurements

A summary of the findings from the computation of the coefficients of kinetic friction for various combinations of resilient floor surface materials and rubber and leather shoe heel sizes loaded with five pounds of weight is presented in Table VIII. The table gives the mean coefficients of friction for individual floor surface materials and heel sizes of rubber and

TABLE VIII

COEFFICIENT OF FRICTION MEASUREMENTS OF RESILIENT FLOOR SURFACE MATERIALS BY DIFFERENT HEEL SIZES OF LEATHER AND RUBBER LOADED WITH FIVE POUNDS OF WEIGHT

Heel material	Heel size	Floor surface material: Linoleum	Vinyl asbestos	Vinyl cork	Grease-proof asphalt	Solid vinyl translucent	Asphalt	Solid vinyl opaque	Rubber	Plain cork	Over-all mean
Leather	Small stacked	.208	.206	.214	.208	.252	.236	.266	.298	.434	.258
	Cuban	.254	.238	.262	.234	.238	.248	.298	.282	.394	.272
	Child's	.274	.274	.288	.310	.284	.296	.330	.362	.440	.318
	Man's	.290	.314	.302	.334	.322	.370	.342	.342	.428	.338
Over-all mean		.256	.258	.266	.272	.274	.288	.308	.320	.424	.296
Rubber	Small stacked	.430	.512	.530	.622	.488	.476	.578	.580	.512	.526
	Cuban	.474	.518	.578	.648	.568	.518	.652	.610	.598	.574
	Child's	.376	.442	.436	.570	.426	.464	.542	.568	.488	.480
	Man's	.392	.450	.456	.584	.440	.470	.548	.552	.512	.490
Over-all mean		.418	.480	.500	.606	.480	.482	.580	.578	.528	.516

of leather. Means were computed for heel sizes of leather and of rubber for individual floor surface materials so that differences could be observed among heels of different sizes and among the various floor surface materials.

Heel materials. The measurements listed in Table VIII indicate a higher coefficient of friction for rubber shoe heel material than for leather shoe heel materials. The over-all mean coefficient of friction extended from .296 for leather to .516 for rubber with a difference of .220 in the over-all mean between the two materials.

Heel sizes. Some of the coefficient of friction measurements for individual floor surface materials increased progressively as the heel size increased. This was true among the leather heels in particular. The over-all mean coefficients of friction for all leather heel sizes increased progressively as the size of the heels increased; however, for rubber heels, the coefficients of friction decreased progressively as the size of the heels increased. The coefficients of friction ranged from .258 for the small stacked heel to .338 for the man's heel among the leather heels while the range extended from .490 for the man's heel to .574 for the cuban heel among the rubber heels.

Floor surface materials. The floor surface materials listed in Table VIII are ranked from those materials with the lowest coefficients of friction to those with the highest coefficients of friction with the leather heels. The order differed with the rubber heels. When tested with leather shoe heel materials, linoleum, with an over-all mean of .256, ranked lowest among all flooring materials tested, while plain cork, with an over-all mean of .424, ranked highest. When tested with rubber heels, the coefficients of friction ranged from .418 for linoleum to .606 for greaseproof asphalt.

II. ANALYSIS OF DATA FOR OTHER WEIGHT LOADS

The pattern for certain sources of variation in the analysis of variance and among the coefficients of friction for the other weight loads was similar to that of the five pound weight load. Therefore, only a comparison of the findings for the eleven, eighteen and one-half, twenty-six, and thirty-three and one-half pound weight loads will be reported. Analysis of variance and coefficients of friction tables for these weight loads are presented in Appendix B.

Summary of the Separate Analyses of Weight Loads

Among the sources of variation in the main plot which were analyzed for all weight loads, the F ratios among replications and between heel materials were highly significant. The shoe heel sizes x materials interaction was also highly significant in the analysis of variance for the five, eleven, and twenty-six pound weight loads. The differences among shoe heel sizes were not significant for any weight load.

Among the sources of variation in the sub-units which were analyzed for all weight loads, the F ratios among floor surfaces, floor surfaces x heel materials interaction, and floor surfaces x heel sizes x materials interaction were highly significant. Floor surfaces x heel sizes interaction was also highly significant for the twenty-six and the thirty-three and one-half pound weight loads. There was no apparent explanation for the significance of this interaction. The means of the force of friction measurements for these interactions are presented in Appendix Tables XX-XXVII.

Among all weight loads tested, the most significant differences among variables existed between heel materials while no significant differences existed among shoe heel sizes.

The hypothesis that there is no difference in the force of friction measurements existing among different heel sizes could not be rejected on the basis that differences among shoe heel sizes were not statistically significant with any weight load applied. However, the hypotheses that there are no differences between heel materials and floor surfaces, and that there are no interactions among floor surfaces and heel materials, among floor surfaces and heel sizes and materials could be rejected on the basis that these sources of variation were highly significant for all weight loads.

Summary and Comparison of the Coefficients of Kinetic Friction Among Weight Loads

The coefficients of friction were greater for rubber shoe heel material than for leather shoe heel material with each weight load applied (Appendix Tables XVI-XIX). The difference in the over-all mean coefficients of friction for the two heel materials increased progressively as the weight load was increased.

The over-all mean coefficients of friction for all leather heel sizes tended to increase as the size of the heel increased; however, for rubber heels, the coefficients of friction tended to decrease as the size of the heels increased. This pattern was observed among the coefficients of friction for each individual weight load.

The floor surface materials could not be ranked in the same order according to coefficients of friction for each weight load applied to the heels. However, linoleum had the lowest coefficient of friction with each weight load applied except the eighteen and one-half pound weight load, while plain cork had the highest coefficient of friction with each weight load. When the three heaviest weight loads were applied to the rubber heels, solid vinyl translucent indicated the lowest coefficient of friction while greaseproof asphalt indicated the highest coefficient of friction with each weight load except the twenty-six pound load.

A comparison of the mean coefficients of friction for the nine resilient floor surface materials tested with all heel sizes of leather and of rubber among weight loads is presented in Table IX. Over-all means of the coefficients of friction for leather and for rubber heel sizes for each weight load are also shown in the table.

No definite pattern could be distinguished among the coefficients of friction for the leather heel sizes tested with various weight loads. However, among the rubber heel sizes tested with the various weight loads, the coefficients of friction tended to increase progressively as the weight loads increased. Consequently, the over-all mean coefficients of friction for all rubber heel sizes increased progressively as the weight loads increased with a range of .200 between the five and thirty-three and one-half pound weight loads.

The table shows that higher coefficients of friction were found for the rubber heels than for the leather heels with the greatest dif-

TABLE IX

COEFFICIENTS OF FRICTION AMONG WEIGHT LOADS FOR ALL HEEL SIZES OF LEATHER AND OF RUBBER TESTED WITH NINE RESILIENT FLOOR SURFACES

Heel material	Heel size	Weight loads				
		5 lbs.	11 lbs.	18.5 lbs.	26 lbs.	33.5 lbs.
Leather	Small stacked	.258	.270	.280	.281	.269
	Cuban	.272	.262	.286	.289	.272
	Child's	.318	.326	.330	.312	.299
	Man's	.338	.348	.343	.427	.374
Over-all mean		.296	.302	.309	.327	.304
Rubber	Small stacked	.526	.601	.697	.702	.715
	Cuban	.574	.708	.674	.758	.781
	Child's	.480	.542	.631	.635	.682
	Man's	.490	.536	.618	.613	.684
Over-all mean		.516	.596	.655	.677	.716

ference of .412 existing between the two materials when tested with thirty-three and one-half pounds of weight.

The mean coefficients of kinetic friction for the various flooring materials tested under clean and dry conditions with heel sizes of leather and of rubber are presented for each weight load in Table X. The over-all means for all of the weight loads are also shown in the table.

Using the over-all means, the materials tested with the rubber heels are ranked with the highest coefficients to those with the lowest as follows: greaseproof asphalt, solid vinyl opaque, rubber, vinyl cork, vinyl asbestos, asphalt, plain cork, solid vinyl translucent, and linoleum. Using the over-all means, the materials tested with the leather heels are ranked from those with the highest coefficients of friction to those with the lowest as follows: plain cork, rubber, solid vinyl opaque, solid vinyl translucent, asphalt, greaseproof asphalt, vinyl asbestos, vinyl cork, and linoleum. It is interesting to note that some materials as linoleum and solid vinyl opaque were ranked in similar positions among leather and rubber heel materials, whereas, other materials as plain cork were ranked in almost opposite positions among the two heel materials.

III. ANALYSIS OF COEFFICIENT OF KINETIC FRICTION MEASUREMENTS AMONG WEIGHT LOADS

The findings from the analysis of variance for the five weight loads applied to each heel size are presented in Table XI.

In this experiment the differences among the mean coefficients of friction for all weight loads were found to be highly significant.

TABLE X

MEAN COEFFICIENTS OF FRICTION FOR RESILIENT FLOOR SURFACE MATERIALS TESTED WITH RUBBER AND LEATHER HEELS LOADED WITH VARIOUS WEIGHT LOADS

Heel material	Weight load	Floor surface material								
		Lino-leum	Vinyl asbestos	Vinyl cork	Grease-proof asphalt	Solid vinyl trans-lucent	Asphalt	Solid vinyl opaque	Rubber	Plain cork
Leather	5 lbs.	.256	.258	.266	.272	.274	.288	.308	.320	.424
	11 lbs.	.252	.261	.255	.267	.288	.285	.313	.335	.458
	18.5 lbs.	.258	.263	.254	.264	.300	.289	.332	.335	.470
	26 lbs.	.269	.288	.282	.295	.317	.307	.345	.369	.473
	33.5 lbs.	.248	.265	.264	.279	.301	.276	.326	.344	.431
Over-all mean		.257	.267	.264	.275	.296	.289	.325	.341	.451
Rubber	5 lbs.	.418	.480	.500	.606	.480	.482	.580	.573	.528
	11 lbs.	.499	.567	.595	.681	.552	.563	.665	.673	.575
	18.5 lbs.	.573	.645	.680	.757	.558	.618	.751	.727	.585
	26 lbs.	.602	.680	.703	.748	.572	.653	.773	.761	.597
	33.5 lbs.	.643	.729	.737	.813	.594	.678	.810	.837	.600
Over-all mean		.547	.620	.643	.721	.551	.599	.716	.714	.577

TABLE XI

ANALYSIS OF VARIANCE OF THE SKID RESISTANCE OF FLOOR SURFACES USING FIVE DIFFERENT WEIGHT LOADS

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among loads	4	3.07	.767	15.65**
Within loads	2156	106.37	.049	
Total	2160	109.44		

**Significant beyond the .1 per cent level.

Since classical laws of friction state that when one solid surface slides over another, the frictional force is proportional to the weight load pressing the surfaces together, no significant differences among the mean coefficients of friction should occur. However, some authors state that a deviation from this law can be expected. The significant differences found in this experiment may have been due, in part, to the greater vibrations of the testing machine with the heaviest weight loads on the rubber heels, an observation made by the researcher.

The hypothesis that there is no difference in the coefficients of friction existing among shoe heels loaded with different weight loads was rejected on the basis that the differences among the mean coefficients of friction for the different weight loads were highly significant.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

I. SUMMARY

The purposes of this study were as follows:

1. To determine the coefficient of friction for different sizes of leather and rubber shoe heels on smooth floor surface materials.

2. To determine whether the coefficient of friction is affected by (a) the size of the shoe heel or (b) the weight load applied to the heel.

The testing apparatus used in collecting data in the experiment was developed specifically for the research project entitled, "Testing of Smooth Floor Surfaces and Finishes From the Standpoint of Safety," for which this experiment served as a pilot study. The testing apparatus made it feasible to secure force of friction measurements for twenty-eight test panels mounted on the testing surface of the machine with one complete revolution of the testing surface. This characteristic of the apparatus distinguished it from other testing apparatus used in previous studies of skid resistance. The machine can be used to measure both kinetic and static friction.

Three test panels of each floor surface material tested were secured from each of two manufacturers of flooring materials to provide a total of six samples of each material. The sample included the following floor surface materials: asphalt, vinyl asbestos, plain cork, vinyl cork, rubber, greaseproof asphalt, battleship linoleum, solid vinyl translucent, and solid vinyl opaque. All of the test panels were sanded to the same degree by a controlled method in order to simulate materials of a worn condition.

Four heel sizes each of leather and of rubber were used in the tests to determine the effects of the area of contact upon the coefficients of kinetic friction. The faces of the heels were sanded to remove surface roughness from the heels. This procedure was considered necessary in order to eliminate the possibility of confounding the test results by allowing the heels to make incomplete contact with the surfaces to be tested. The order of testing the heel sizes of leather and of rubber and of the flooring materials was randomized.

Five weight loads were used on each heel size of leather and of rubber to test differences in force of friction measurements among weight loads. The heels were loaded with increasing weight loads during the testing procedure.

An effort was made to prepare the flooring materials and heels so that accurate test results would be obtained. All test panels were washed and allowed to dry thoroughly before the testing procedure. The heel and floor panels were cleaned before each series of tests in which they were used.

A total of eighty tests were conducted in the experiment providing 8,960 force of friction measurements.

Analysis of variance was the statistical test employed in analyzing the data collected in the experiment. Two separate analysis of variance models were used in order to analyze the data by individual weight loads and among weight loads. The means of the force of friction measurements were analyzed by individual weight loads and the coefficients of kinetic friction were used to analyze the data among weight loads. The coefficient of friction measurements also provided a basis for comparing the floor surface and heel materials in the four different sizes and ranking them according to skid resistance under the conditions of the experiment.

Highly significant differences were found in the mean force of friction measurements between leather and rubber heel materials and among resilient smooth floor surface materials including linoleum, vinyl asbestos, vinyl cork, greaseproof asphalt, solid vinyl translucent, asphalt, solid vinyl opaque, rubber, and plain cork. The rubber heel materials consistently indicated a higher force of friction measurement than leather heel material when tested with floor surface materials in a dry and worn condition.

The floor surface materials could not be ranked in the same order according to the force of friction measurements among heel materials nor among weight loads. However, in the over-all results, plain cork and greaseproof asphalt indicated the highest force of friction measurements while linoleum had the lowest.

No significant differences in the mean force of friction measurements were found among the small stacked, cuban, child's, and man's heels. However, force of friction measurements for the floor surface materials tended to increase as the size of the leather heel increased but to decrease with an increase in the size of the rubber heels.

Significant differences were found in the mean coefficients of friction among the five different weight loads applied to the heels, including five, eleven, eighteen and one-half, twenty-six, and thirty-three and one-half pounds. The coefficients of friction for the floor surface materials and heel materials increased when the heavier weight loads were applied to the heels.

II. CONCLUSIONS

From the results of this experiment in which nine resilient smooth floor surfaces--asphalt, vinyl asbestos, plain cork, vinyl cork, rubber, greaseproof asphalt, battleship linoleum, solid vinyl translucent, and solid vinyl opaque--were tested with rubber and leather heel sizes loaded with five different weight loads, the following conclusions are drawn:

(1) Rubber heel material has greater skid resistance than leather heel material.

(2) Among the floor surface materials tested, greaseproof asphalt and plain cork have the greatest skid resistance while linoleum has the least skid resistance among the flooring materials.

(3) Floor surface materials and heel materials do not have a single force of friction measurement but depend upon the floor surface material to which the heel is applied.

(4) The size of the heel is not a significant factor in determining the force of friction existing between floor surface and heel materials.

(5) The skid resistance of two given materials increases with an increase in the vertical force pressing the materials together.

III. RECOMMENDATIONS

The need for further study of skid resistance of smooth floor surface materials is apparent from the findings of this experiment. Since the experiment served as a pilot study to the research project, "Testing of Smooth Floor Surfaces From the Standpoint of Safety," it is recommended:

(1) That a study be made to test other variables which may affect the skid resistance of floor surface materials including the testing of floor surface materials in a dry and wet condition, waxed and unwaxed condition, and in a new condition with a variety of heel materials to provide a more comprehensive study of skid resistance to use as a basis for ranking the materials tested according to skid resistance and for comparing the results with the findings of other studies.

(2) That a study be made to determine gloss values of waxed and unwaxed floor surface materials and to correlate these results with coefficients of friction.

(3) That heel sizes of different materials be tested and analyzed separately in order to determine whether significant differences exist among the coefficients of friction for individual heel materials of different sizes.

In relation to the testing machine, it is recommended that:

(1) A study similar to the present study be made using continuous sheets of floor surface materials on the testing surface of the machine in order to insure uniformity of motion of the heels as the testing surface revolves beneath them.

(2) A study be conducted using continuous sheets of floor surface materials to which a range of weight loads are applied to shoe heels and in which the velocity of the testing machine is varied.

(3) Further study be made of the testing apparatus when used to test heavy weight loads on rubber heels and other heel materials containing either natural or synthetic rubber.

(4) A study using this machine be made of the coefficients of static friction of floor surface and heel materials in order to compare kinetic and static coefficients of friction and to compare with the results obtained from other machines.

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APPENDIX A

FORMULAS USED IN COMPUTING ANALYSES OF VARIANCE

BY INDIVIDUAL WEIGHT LOADS

Among replicates sum of squares.

$$\frac{\sum_{i=1}^{r} R^2_i}{abc} - \frac{T^2}{N} = R$$

Among shoe heel sizes sum of squares.

$$\frac{\sum_{j=1}^{a} A^2_j}{rbc} - \frac{T^2}{N} = A$$

Between heel materials sum of squares.

$$\frac{\sum_{k=1}^{b} B^2_k}{rac} - \frac{T^2}{N} = B$$

Shoe heel sizes x materials interaction sum of squares.

$$\frac{\sum_{j=1}^{a} \sum_{k=1}^{b} T^2_{jk}}{rc} - \frac{T^2}{N} - A - B = AB$$

Error (a) sum of squares.

$$\sum_{i=1}^{r} \sum_{j=1}^{a} \sum_{k=1}^{b} (X_{ijk})^2 - \frac{T^2}{N} - R - A - B - AB$$

Among floor surfaces sum of squares.

$$\frac{\sum C^2_l}{rab} - \frac{T^2}{N} = C$$

Floor surfaces x heel sizes interaction sum of squares.

$$\frac{\sum_{j=1}^{a} \sum_{l=1}^{c} T^2_{jl}}{rb} - \frac{T^2}{N} - A - C = AC$$

Floor surfaces x heel materials interaction sum of squares.

$$\frac{\sum_{k=1}^{b} \sum_{l=1}^{c} T^2_{kl}}{ra} - \frac{T^2}{N} - C - B = BC$$

Floor surfaces x heel sizes x materials interaction sum of squares.

$$\frac{\sum_{j=1}^{a} \sum_{k=1}^{b} \sum_{l=1}^{c} T^2_{jkl}}{r} - \frac{T^2}{N} - A - B - C = ABC$$

Total sum of squares.

$$\sum_{i=1}^{r} \sum_{j=1}^{a} \sum_{k=1}^{b} \sum_{l=1}^{c} (X_{ijkl})^2 - \frac{T^2}{N}$$

Error (b) sum of squares.

Total sum of squares - R - A - B - AB - Error (a) - C - AC - BC - ABC where

i is associated with replicates
j is associated with heel sizes
k is associated with heel materials
l is associated with floor surfaces

T = total of all measurements

R_i = total of all measurements in the ith replicate

T_{jkl} = entry in the jklth cell of the a x b x c table, this entry being the total of all measurements associated with the jth level of factor a, the kth level of factor b and the lth level of factor c

T_{jk} = entry in the jkth cell of the a x b table, this entry being the total of all measurements associated with the jth level of factor a and the kth level of factor b

T_{jl} = entry in the jlth cell of the a x c table, this entry being the total of all measurements associated with the jth level of factor a and the lth level of factor c

T_{kl} = entry in the klth cell of the b x c table, this entry being the total of all measurements associated with the kth level of factor b and the lth level of factor c

A_j = total of all measurements associated with the jth level of factor a

B_k = total of all measurements associated with the kth level of factor b

C_l = total of all measurements associated with the lth level of factor c.[1]

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[1]Bernard Ostle, Statistics in Research (Ames, Iowa: The Iowa State College Press, 1954), p. 352.

FORMULAS USED IN COMPUTING ANALYSIS OF VARIANCE
AMONG WEIGHT LOADS

Among weight loads sum of squares.

$$\frac{\sum A^2}{N} - \frac{T^2}{N} = A$$

Total sum of squares.

$$\sum (X)^2 - \frac{T^2}{N} = B$$

Within loads sum of squares.

$$B - A = C$$

APPENDIX B

TABLE XII

ANALYSIS OF VARIANCE OF FORCE OF FRICTION MEASUREMENTS OF FLOOR SURFACES WITH DIFFERENT HEEL SIZES OF LEATHER AND RUBBER LOADED WITH ELEVEN POUNDS OF WEIGHT

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among replicates	5	150.91	30.18	13.18**
Among shoe heel sizes	3	21.58	7.19	3.14
Between heel materials	1	1146.06	1146.06	500.46**
Shoe heel sizes x materials interaction	3	138.97	46.32	20.23**
Error (a)	35	80.06	2.29	
Sub-units				
Among floor surfaces	8	106.10	13.26	51.00**
Floor surfaces x heel sizes interaction	24	7.50	.31	1.19
Floor surfaces x heel materials interaction	8	81.07	10.13	38.96**
Floor surfaces x heel sizes x materials interaction	24	238.31	99.30	381.92**
Error (b)	320	83.58	.26	
Total	431	2054.14		

**Significant beyond the .1 per cent level.

TABLE XIII

ANALYSIS OF VARIANCE OF FORCE OF FRICTION MEASUREMENTS OF FLOOR SURFACES WITH DIFFERENT HEEL SIZES OF LEATHER AND RUBBER LOADED WITH EIGHTEEN AND ONE-HALF POUNDS OF WEIGHT

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among replicates	5	749.30	149.86	9.65**
Among shoe heel sizes	3	1.87	.62	.04
Between heel materials	1	4407.95	4407.95	283.83**
Shoe heel sizes x materials interaction	3	129.62	43.21	2.78
Error (a)	35	543.56	15.53	
Sub-units				
Among floor surfaces	8	310.89	38.86	24.44**
Floor surfaces x heel sizes interaction	24	59.01	2.46	1.55
Floor surfaces x heel materials interaction	8	399.54	49.94	31.41**
Floor surfaces x heel sizes x materials interaction	24	242.75	26.78	16.84**
Error (b)	320	509.92	1.59	
Total	431	7754.41		

**Significant beyond the .1 per cent level.

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TABLE XIV

ANALYSIS OF VARIANCE OF FORCE OF FRICTION MEASUREMENTS OF FLOOR SURFACES WITH DIFFERENT HEEL SIZES OF LEATHER AND RUBBER LOADED WITH TWENTY-SIX POUNDS OF WEIGHT

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among replicates	5	1545.66	309.13	10.15**
Among shoe heel sizes	3	124.60	41.53	1.36
Between heel materials	1	8916.56	8916.56	292.63**
Shoe heel sizes x materials interaction	3	850.21	283.40	9.30**
Error (a)	35	1066.61	30.47	
Sub-units				
Among floor surfaces	8	561.91	70.24	61.61**
Floor surfaces x heel sizes interaction	24	167.49	6.98	6.12**
Floor surfaces x heel materials interaction	8	692.26	86.53	75.90**
Floor surfaces x heel sizes x materials interaction	24	1829.30	76.22	66.86**
Error (b)	320	366.06	1.14	
Total	431	16120.65	37.40	

**Significant beyond the .1 per cent level.

TABLE XV

ANALYSIS OF VARIANCE OF FORCE OF FRICTION MEASUREMENTS OF FLOOR SURFACES WITH DIFFERENT HEEL SIZES OF LEATHER AND RUBBER LOADED WITH THIRTY-THREE AND ONE-HALF POUNDS OF WEIGHT

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among replicates	5	2918.05	583.61	5.73**
Among shoe heel sizes	3	164.88	54.96	.54
Between heel materials	1	20569.31	20569.31	201.98**
Shoe heel sizes x materials interaction	3	666.66	222.22	2.18
Error (a)	35	3564.48	101.84	
Sub-units				
Among floor surfaces	8	1106.17	138.27	25.75**
Floor surfaces x heel sizes interaction	24	307.37	12.81	2.39**
Floor surfaces x heel materials interaction	8	1431.93	178.99	33.33**
Floor surfaces x heel sizes x materials interaction	24	2644.65	110.19	20.52**
Error (b)	320	1718.99	5.37	
Total	431	35092.49		

**Significant beyond the .1 per cent level.

TABLE XVI

COEFFICIENT OF FRICTION MEASUREMENTS OF RESILIENT FLOOR SURFACE MATERIALS BY DIFFERENT HEEL SIZES OF LEATHER AND RUBBER LOADED WITH ELEVEN POUNDS OF WEIGHT

Heel material	Heel size	Floor surface material									Over-all mean
		Lino-leum	Vinyl cork	Vinyl asbestos	Grease-proof asphalt	Asphalt	Solid vinyl trans-lucent	Solid vinyl opaque	Rubber	Plain cork	
Leather	Small stacked	.210	.214	.211	.210	.235	.275	.280	.321	.475	.270
	Cuban	.220	.221	.220	.229	.235	.225	.282	.290	.431	.262
	Child's	.269	.278	.278	.288	.313	.312	.342	.371	.487	.326
	Man's	.310	.309	.336	.342	.357	.339	.345	.355	.440	.348
Over-all mean		.252	.255	.261	.267	.285	.288	.313	.335	.458	.302
Rubber	Small stacked	.512	.635	.579	.677	.555	.558	.663	.655	.576	.601
	Cuban	.612	.711	.681	.765	.661	.704	.785	.794	.661	.708
	Child's	.434	.520	.503	.645	.525	.484	.615	.638	.513	.542
	Man's	.436	.516	.507	.638	.510	.465	.599	.604	.552	.536
Over-all mean		.499	.595	.567	.681	.563	.552	.665	.673	.575	.596

TABLE XVII

COEFFICIENT OF FRICTION MEASUREMENTS OF RESILIENT FLOOR SURFACE MATERIALS BY DIFFERENT HEEL SIZES OF LEATHER AND RUBBER LOADED WITH EIGHTEEN AND ONE-HALF POUNDS OF WEIGHT

Heel material	Heel size	Floor surface material									Over-all mean
		Vinyl cork	Lino-leum	Vinyl asbestos	Grease-proof asphalt	Asphalt	Solid vinyl trans-lucent	Solid vinyl opaque	Rubber	Plain cork	
Leather	Small stacked	.229	.224	.211	.210	.233	.276	.300	.336	.495	.280
	Cuban	.221	.226	.233	.241	.256	.269	.317	.339	.468	.286
	Child's	.271	.269	.281	.282	.310	.321	.348	.395	.493	.330
	Man's	.293	.313	.330	.326	.360	.332	.361	.351	.422	.343
Over-all mean		.254	.258	.263	.264	.289	.300	.332	.355	.470	.309
Rubber	Small stacked	.743	.646	.693	.725	.682	.671	.715	.749	.653	.697
	Cuban	.698	.606	.683	.721	.625	.571	.812	.729	.566	.674
	Child's	.663	.539	.611	.741	.604	.517	.721	.716	.569	.631
	Man's	.618	.500	.593	.790	.562	.473	.757	.715	.554	.618
Over-all mean		.680	.573	.645	.757	.618	.558	.751	.727	.585	.655

TABLE XVIII

COEFFICIENT OF FRICTION MEASUREMENTS OF RESILIENT FLOOR SURFACE MATERIALS BY DIFFERENT HEEL SIZES OF LEATHER AND RUBBER LOADED WITH TWENTY-SIX POUNDS OF WEIGHT

Heel material	Heel size	Floor surface material									Over-all mean
		Linoleum	Vinyl cork	Vinyl asbestos	Grease-proof asphalt	Asphalt	Solid vinyl translucent	Solid vinyl opaque	Rubber	Plain cork	
Leather	Small stacked	.217	.235	.218	.226	.241	.280	.288	.323	.504	.281
	Cuban	.231	.224	.244	.230	.260	.280	.318	.333	.480	.289
	Child's	.253	.267	.275	.265	.304	.317	.322	.350	.454	.312
	Man's	.377	.402	.417	.457	.423	.388	.450	.471	.453	.427
Over-all mean		.269	.282	.288	.295	.307	.317	.345	.369	.473	.327
Rubber	Small stacked	.677	.740	.712	.661	.710	.668	.756	.772	.617	.702
	Cuban	.675	.757	.770	.821	.743	.645	.867	.848	.692	.758
	Child's	.549	.654	.637	.764	.602	.506	.741	.717	.542	.635
	Man's	.505	.662	.602	.749	.556	.469	.726	.708	.539	.613
Over-all mean		.602	.703	.680	.748	.653	.572	.773	.761	.597	.677

TABLE XIX

COEFFICIENT OF FRICTION MEASUREMENTS OF RESILIENT FLOOR SURFACE MATERIALS BY DIFFERENT HEEL SIZES OF LEATHER AND RUBBER LOADED WITH THIRTY-THREE AND ONE-HALF POUNDS OF WEIGHT

Heel material	Heel size	Floor surface material									Over-all mean
		Lino-leum	Vinyl cork	Vinyl asbestos	Asphalt	Grease-proof asphalt	Solid vinyl trans-lucent	Solid vinyl opaque	Rubber	Plain cork	
Leather	Small stacked	.210	.236	.210	.218	.228	.262	.292	.316	.353	.269
	Cuban	.219	.235	.240	.232	.241	.280	.314	.315	.371	.272
	Child's	.242	.243	.258	.292	.253	.308	.315	.344	.440	.299
	Man's	.319	.343	.352	.360	.393	.354	.384	.400	.463	.374
Over-all mean		.248	.264	.265	.276	.279	.301	.326	.344	.431	.304
Rubber	Small stacked	.706	.743	.742	.712	.695	.659	.740	.816	.624	.715
	Cuban	.707	.778	.797	.786	.831	.679	.858	.922	.676	.781
	Child's	.592	.693	.687	.635	.820	.543	.809	.807	.549	.682
	Man's	.568	.736	.689	.581	.904	.494	.834	.801	.552	.684
Over-all mean		.643	.737	.729	.678	.813	.594	.810	.837	.600	.716

TABLE XX

MEAN FORCE OF FRICTION MEASUREMENTS FOR LEATHER AND RUBBER HEELS OF VARIOUS SIZES LOADED WITH ELEVEN POUNDS OF WEIGHT

Heel size	Heel material	
	Leather	Rubber
Stacked	2.97	9.58
Cuban	2.88	10.67
Child's	3.59	9.55
Man's	3.83	9.73

TABLE XXI

MEAN FORCE OF FRICTION MEASUREMENTS FOR LEATHER AND RUBBER HEELS OF VARIOUS SIZES LOADED WITH TWENTY-SIX POUNDS OF WEIGHT

Heel size	Heel material	
	Leather	Rubber
Stacked	7.31	18.24
Cuban	7.51	19.70
Child's	8.11	16.50
Man's	11.09	15.93

TABLE XXII

MEAN FORCE OF FRICTION MEASUREMENTS FOR FLOOR SURFACE MATERIALS AND VARIOUS HEEL SIZES LOADED WITH TWENTY-SIX POUNDS OF WEIGHT

Heel size	Floor surface material								
	Linoleum	Grease-proof asphalt	Vinyl asbestos	Solid vinyl translucent	Asphalt	Solid vinyl opaque	Vinyl cork	Rubber	Plain cork
Stacked	11.62	11.53	12.08	12.33	12.36	13.58	12.67	14.23	14.57
Cuban	11.78	13.66	13.18	12.02	13.05	15.40	12.76	15.36	15.23
Child's	10.42	13.37	11.86	10.70	11.78	13.82	11.96	13.87	12.95
Man's	11.46	15.68	13.24	11.15	12.73	15.30	13.83	15.31	12.90

TABLE XXIII

MEAN FORCE OF FRICTION MEASUREMENTS FOR FLOOR SURFACE MATERIALS AND VARIOUS HEEL SIZES LOADED WITH THIRTY-THREE AND ONE-HALF POUNDS OF WEIGHT

Heel size	Floor surface material								
	Linoleum	Solid vinyl translucent	Asphalt	Vinyl asbestos	Plain cork	Vinyl cork	Solid vinyl opaque	Rubber	Grease-proof asphalt
Stacked	15.32	15.41	15.59	15.94	17.97	16.39	17.29	18.85	15.45
Cuban	15.52	16.05	17.04	17.36	17.52	16.97	19.61	20.72	17.96
Child's	13.97	14.23	15.52	15.83	16.55	15.66	18.81	19.27	17.96
Man's	14.86	14.20	15.76	17.42	17.01	18.08	20.40	20.11	21.72

TABLE XXIV

MEAN FORCE OF FRICTION MEASUREMENTS FOR FLOOR SURFACES AND LEATHER AND RUBBER HEELS LOADED WITH ELEVEN POUNDS OF WEIGHT

Heel material	Floor surface material								
	Lino-leum	Vinyl cork	Vinyl as-bestos	Grease-proof asphalt	As-phalt	Solid vinyl trans-lucent	Solid vinyl opaque	Rubber	Plain cork
Leather	2.77	2.82	2.87	2.96	3.14	3.17	3.44	3.68	5.04
Rubber	5.47	6.55	6.24	7.49	6.19	6.20	7.32	7.40	6.33

TABLE XXV

MEAN FORCE OF FRICTION MEASUREMENTS FOR FLOOR SURFACES AND LEATHER AND RUBBER HEELS LOADED WITH EIGHTEEN AND ONE-HALF POUNTS OF WEIGHT

Heel material	Floor surface material								
	Vinyl cork	Lino-leum	Vinyl as-bestos	Grease-proof asphalt	As-phalt	Solid vinyl trans-lucent	Solid vinyl opaque	Rubber	Plain cork
Leather	4.69	4.77	4.87	4.89	5.35	5.54	6.13	6.56	8.69
Rubber	12.58	10.59	11.92	14.00	11.43	10.32	13.89	13.44	10.82

TABLE XXVI

MEAN FORCE OF FRICTION MEASUREMENTS FOR FLOOR SURFACES AND LEATHER AND RUBBER HEELS LOADED WITH TWENTY-SIX POUNDS OF WEIGHT

Heel material	Floor surface material								
	Lino-leum	Vinyl cork	Vinyl as-bestos	Grease-proof asphalt	As-phalt	Solid vinyl trans-lucent	Solid vinyl opaque	Rubber	Plain cork
Leather	7.00	7.33	7.50	7.66	7.99	8.23	8.99	9.60	12.29
Rubber	15.64	18.27	17.68	19.46	16.97	14.87	20.09	19.79	15.53

TABLE XXVII

MEAN FORCE OF FRICTION MEASUREMENTS FOR FLOOR SURFACES AND LEATHER AND RUBBER HEELS LOADED WITH THIRTY-THREE AND ONE-HALF POUNDS OF WEIGHT

Heel material	Floor surface material								
	Lino-leum	Vinyl cork	Vinyl as-bestos	As-phalt	Grease-proof asphalt	Solid vinyl trans-lucent	Solid vinyl opaque	Rubber	Plain cork
Leather	8.29	8.85	8.91	9.23	9.33	10.07	10.93	11.50	14.42
Rubber	21.54	24.70	24.41	22.72	27.22	19.88	27.13	28.01	20.10